PRELIMINARY STUDIES OF THE IONOSPHERIC EFFECT FROM THE IONOSPHERIC REGIONS USING GPS PERMANENT TRACKING STATIONS

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ABSTRACT

The Global Positioning System signals must travel through the earth's ionosphere on their way to GPS receivers on or near the earth's surface. The ionosphere is a shell of electron, and electrically charged atoms and molecules that surround the earth, stretching from a height of about 50 km to more than 1000 km above the earth's surface. When the GPS signals propagate through the ionosphere, they suffer an extra time delay as a result of their encounter with the free electrons. This time delay is determined by the density of electrons, which is characterised by the number of electrons in a vertical column with a cross-sectional area of one square metre. This number is called the Total Electron Content (TEC). The dispersive nature of the ionosphere makes it possible to measure its TEC using dual-frequency GPS observations collected by permanent GPS network. Therefore, the main objective of the experiment is to estimate the TEC values from dual-frequency GPS observables with respect to the characteristics of the ionospheric layers. Here, we have used carrier phase observations data from four station of the Malaysian GPS Active System (MASS), namely UiTM Arau, Bukit Pak Apil Kuala Terengganu, UTM Johor and USM, Penang to derive regional TEC values by using the Bernese softwares. The results have shown that approximately 0.5 – 0.6 TECU in TIDs Indicator Value for Peninsular Malaysia. This ionospheric information can be used for environmental studies (e.g. continuous weather monitoring and climatology), microwave communication signals and other geoscience applications.

Keywords: Ionospheric effect, GPS signals, Total Electron Content, Ionospheric regions

INTRODUCTION

Global Positioning System is satellite based positioning system, which has been developed by the US Department of Defense (DoD) for real time navigation since the end of the 70's. It has made a strong impact on the geodetic world. The main goal of the GPS is to provide worldwide, all weather, continuous radio navigation support to users to determine position, velocity and time throughout the world. It consists of three segments: the space, control and user segment. The GPS can be used for absolute and relative geodetic point positioning. Its primary task is to measure distances between 24 satellites in known orbits about 20,000 km above the earth and provide the user with the information of determining user's position, expressed in the geocentric 3D coordinate system (WGS84) **[1,8]**.

Each GPS satellites carries four atomic clocks set to a fundamental frequency, f_o, of 10.23 MHz. Two coherent microwave radio signals are created, termed L1, at a frequency of 1.57542 GHz (154 f_o), and L2, at 1.2276 GHz (120 f_o); these are the carrier signals and are simple sinusoidal waves **[1,8]**. The pure sinusoids cannot be used readily to determine positions in real time. For a user to obtain positions independently in real time, the signals must be modulated, that is, the pure sinusoid must be altered in such a way that time delay measurements can be made. This is achieved by modulating the carriers with pseudo random noise (PRN) codes. Each satellite will transmit two different PRN codes: the C/A (coarse acquisition) code and the P (precision) code.

The precision of a range measurement is determined in part by the wavelength of the chips in the PRN code. Higher precision can be obtained with shorter wavelengths. The GPS transmits the P-code, which has a wavelength of 30 metres, with the chip rate being 10.23 million per second, or 10 times higher than the C/A code. The P-code is transmitted on both L1 and L2, whereas the C/A code is modulated only upon the L1 carrier and is purposely omitted from L2. This omission allows the system owner to control the information broadcast by satellite, and thus denies full system accuracy to unauthorised users **[11]**.

The ionising action of the sun's radiation on the earth's upper atmosphere produces free electrons. Above about 50km the number of free electrons is sufficient to affect the propagation of electromagnetic waves and these 'ionised' region of the atmosphere is a plasma and is referred to as the 'ionosphere', **[6]**. Shorter wavelength signals, such as GPS signals pass through the ionosphere but are affected by it. Different regions of the ionosphere are produced by different chemical species. The ionosphere is composed of the D, E, F1 and F2 regions. Figure 1 illustrates the different regions of the ionosphere. The major characteristics and importance of each

1) D-region, 50 – 90 km: This region, produced by ionisation of several molecular species from hard x-rays and solar Lyman α radiations, causes absorption of radio signals at frequencies up to low VHF band and has no measurable effect on GPS frequencies.
2) E-Region, 90-140 km: The normal E region, produced by solar soft x-rays, has a minimal effect on GPS. An intense E region, with irregular structure, produced by solar particle precipitation in the auroral region, might cause minor scintillation effects. Sporadic E, still unknown origin, is very thin and also has a negligible effect at GPS frequencies.
3) F1-region, 140-210 km: The normal F1 region, combined with the E region, can account for up to 10% of the ionospheric delay encounted by GPS. Diffusion is not important at F1 region heights and, as with the normal E region, it has ahighly predictable density of molecular species, and its electron density merges into the bottom-side of the F2 region.
4) F2-region, 210-1000km: The F2 region is the most dense and also has the highest variability, causing most of the observed effects on GPS receivers. The height of the peak of the electron density of the F2 region generally varies from 250 to 400 km, but it can be even much higher or somewhat lower under extreme conditions. The F2 region is produced atmosphere at those heights. The F2. and to some extent the F1, regions, cause most of the problems for radio-wave propagation at GPS frequencies.

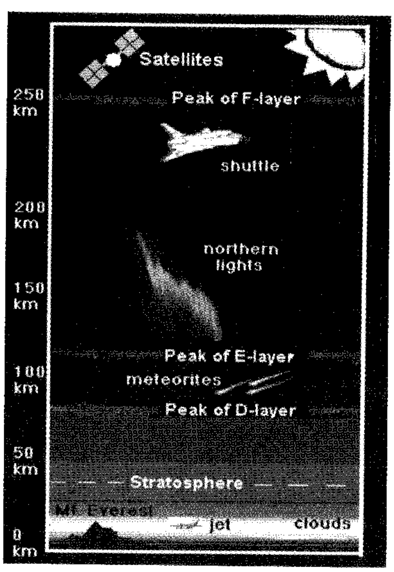

FIGURE 1: The different regions of the ionosphere
(Source: www.rcr.:.rl.ac.uk/ionospheric/what.htm)

In GPS positioning and navigation, the ionosphere can be the largest source of errors. The main ionospheric effects on GPS signals are phase advance (for carrier phase) and group delay (for pseudo range). Here, when radio waves propagate through the atmosphere they suffer an extra time delay. This extra time delay is characterized by the Total Electron Content (TEC). Therefore, it can be stated that the ionospheric delay is a function of the TEC along the signal path and the frequency of the propagated signal – Figure 2. Since the ionosphere is a dispersive medium for radio waves, a dual-frequency GPS receiver can eliminate (to the first order) ionospheric delay through a linear combination of L1 and L2 observables **[6]**. On the other hand, taking advantage of this, the dual-frequency GPS receiver can be used to estimate the TEC along the path from the receiver to each GPS satellite track. These TEC estimates can be used to: 1) study the ionosphere in environmental aspect, or 2) generate an ionosphere model for single-frequency GPS users.

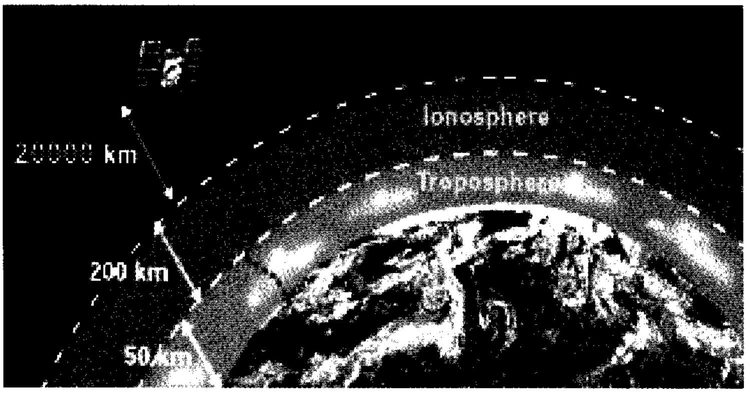

FIGURE 2: Ionospheric refraction causes the GPS signal propagation delays

Mathematically, TEC is expressed as the integrated electron content along the radio signal path, **[6]**:

$$\mathrm{TEC} = \int_S^R n_e(s)ds \qquad (1)$$

where n_e is the electron density in the units of electron/m^3 and ds is the infinitesimal line element. The electron density is a function of the amount of incident solar radiation. Throughout the day, TEC at a location is dependent on the local time, reaching a maximum between 12:00 and 16:00. TEC is measured in units of 10^{16} electrons per m^2. This paper describes the preliminary studies of the ionospheric effect from the ionospheric regions using the dual-frequency GPS observations collected by permanent network stations such as Malaysian Active Satellite System (MASS).

THE DATA SET

A set of data from the 4 stations of the MASS network has been used and analysed. The stations are listed in Table 1.

TABLE 1: List of MASS stations used for data analysis

Location	**Latitude**	**Longitude**	**Ellipsoidal Height (m)**
UiTM Arau, Perlis	6° 27' 00.57"	100° 16' 47.05"	18.12
Bukit Pak Apil, Terengganu	5° 19' 08.28"	103° 08' 21.16"	49.20
UTM, Skudai, Johor	1° 33' 56.43"	103° 38' 22.13"	87.60
USM, Pulau Pinang	5° 21' 28.04"	100° 18' 14.51"	34.50

RESULTS AND DISCUSSION

We used Bernese GPS Version 4.0 software to detect bad points and cycle slips, repair cycle slips and adjust phase ambiguities. All results are shown in the TIDs (Travelling Ionospheric Disturbances) Indicator values (TECU) : 1 TECU = 10^{16} e/m^2. This software supports two types of ionosphere models to represent the deterministic component of the ionosphere such as the local models based on two-dimensional Taylor series expansions and global models based on spherical harmonic expansions. For this study, the global ionospheric has been used to estimate the TEC values:

$$E(\beta, s) = \sum_{n=0}^{n_{max}} \sum_{m=0}^{n} \tilde{P}_{nm}(\sin\beta).(a_{nm} \cos ms + b_{nm} \sin ms) \tag{2}$$

where n_{max} - is the maximum degree of the spherical harmonic expansion

$\bar{P}_{nm} = \Lambda(n, m)$ - P_{nm} are the *normalized* associated *Legendre* functions of degree n and order m based on the normalized function Λ(n,m) and *Legendre* functions P_{nm}, and

a_{nm}, b_{nm} - are the (unknown) TEC coefficients of the spherical harmonics, i.e. the global ionosphere model parameters to be estimated.

The TIDs are wavelike structures, which may imply variations in the ionospheric electron density of several percent of the total electron content. Large scale TIDs (LSTIDs) have horizontal phase speeds of 300 – 1000 m/s, periods ranging from 30 min – 3 hour and horizontal wavelenght exceeding 1000 km. They propagate equatorward from the polar-regions, where they are supposed to be generated in the auroral zones. Medium-scale TIDs (MSTIDs) have horizontal phase speeds of 100 – 300 m/s, periods from 12 min to about 1 hour and horizontal wavelengths of several hundreds of km. They occur much more frequently than LSTIDs and their origin is not known, although many possible excitation mechanisms have been proposed.

We investigated the effects using different of ionospheric regions, which plays an important role in computing the coordinates of the subionospheric points. The single layer ionospheric model assumes that a thin spherical shell can approximate the vertical TEC, which is located at a specified height above the surface of earth. This altitude is often assumed to correspond to the maximum electron density of the ionosphere. Futhermore, it is usually assumed that the ionospheric shell height has no temporal or geographical variation, and therefore it is set to a constant value regardless of the time or location of interest. In our investigation, we tried to estimate the TEC values at fixed heights of D-region 70 km, E-region 120 km, F1-region 180 km and F2-region 500 km. The results for all ionospheric regions are shown in Table 2.

TABLE 2: TIDs Indicator values for different ionospheric region and shell height

Region	Height (km)	TIDs Indicator (TECU)	
		12/12/1999	13/12/1999
D	70	0.64	0.67
E	120	0.60	0.64
F1	180	0.57	0.62
F2	500	0.51	0.58

From Table 2 it can be seen that the maximum TIDs Indicator values on the 12/12/1999 is occurred at the D region 0.64 TECU and minimum values is F2 region 0.51 TECU. While the maximum TIDs Indicator values for the 13/12/1999 is at the D region 0.67 TECU and minimum values is at F2 region 0.58 TECU. These differences may due to the solar activities, whereby the sunspots number for 12/12/1999 is 90 and the solar flux is 150, and for 13/12/1999, the sunspots number is 105 and the solar flux is 163. Graphically its can be seen in Figure 3.

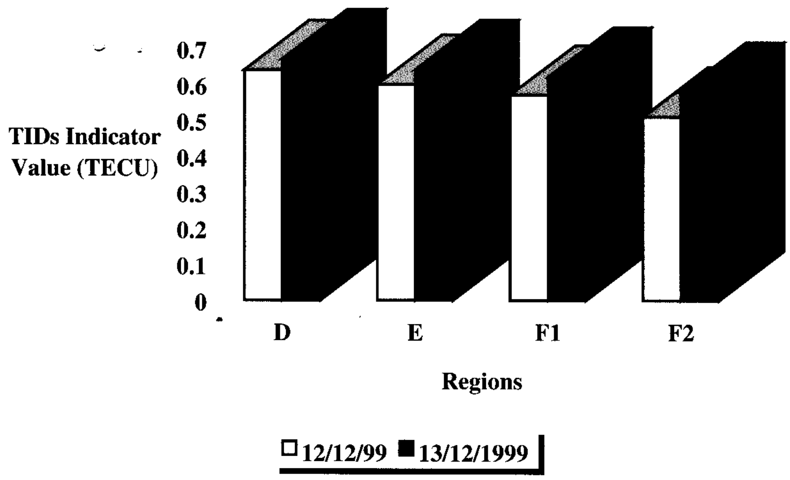

FIGURE 3: TIDs Indicator values for different region

The result have shown that the TIDs Indicator values for both days at the F2-region is smaller than the D, E and F1 region, however, the electron contents at F2-region is greater than the others region – see Table 3.

TABLE 3: TEC values for different ionospheric region and shell height

Region	Height (km)	TEC values (TECU)	
		12/12/1999	13/12/1999
D	70	7 – 23	8 – 18
E	120	10 – 24	16 – 25
F1	180	8 – 21	21 – 30
F2	500	8 – 14	37 – 51

From the above table, it is shown that the results for the TEC values in Table 3 on 12/12/1999 vary from 7 to 24 TECU for D, E, F1 and F2-region. While for 13/12/1999 the TEC values vary from 8 to 51 TECU. Table 3 also shows that there are no significant differences between the TEC values for all regions on the 12/12/1999 compared to the TEC values on 13/12/1999. Perhaps, it may due to the minimum solar activities on the 12/12/1999 compared to 13/12/1999. The Total Electron Content map for the Peninsular Malaysia for 12/12/1999 and 13/12/1999 have been plotted in Figures 4 to 11.

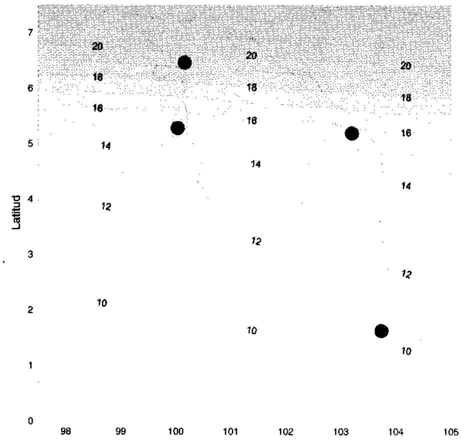

FIGURE 4: Peninsular Malaysia TEC maps at D-region on 12/12/1999

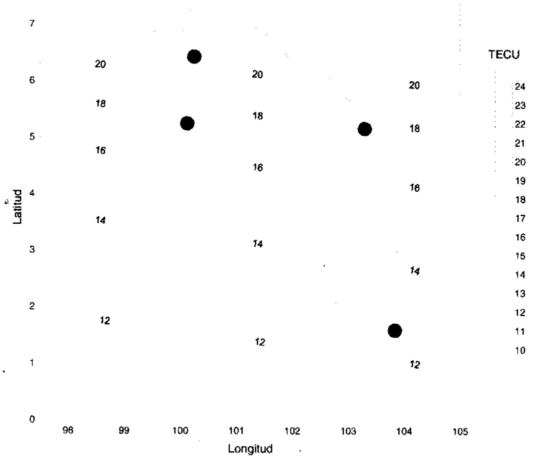

FIGURE 5: Peninsular Malaysia TEC maps at E-region on 12/12/1999

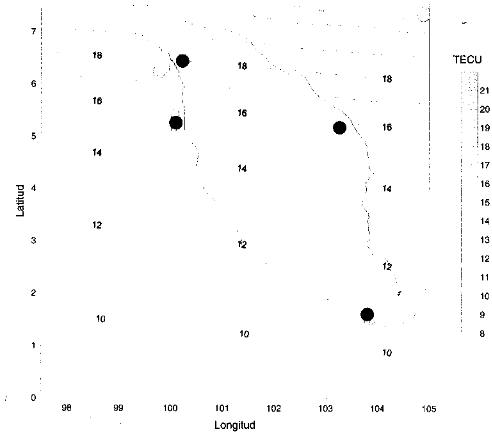

FIGURE 6: Peninsular Malaysia TEC maps at F1-region on 12/12/1999

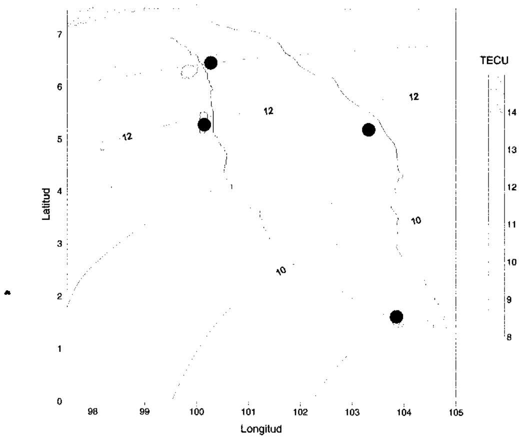

FIGURE 7: Peninsular Malaysia TEC maps at F2-region on 12/12/1999

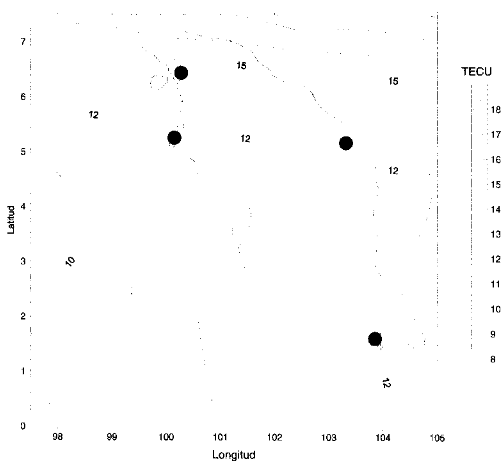

FIGURE 8: Peninsular Malaysia TEC maps at D-region on 13/12/1999

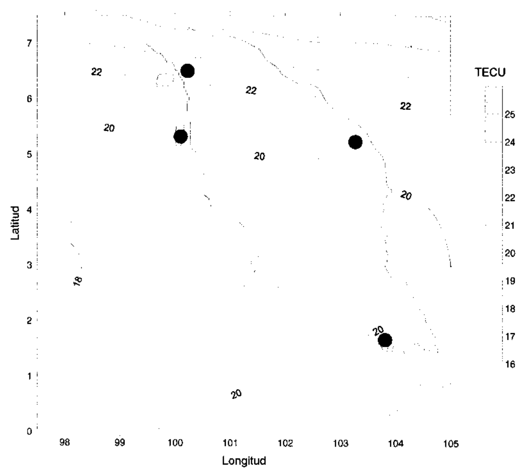

FIGURE 9: Peninsular Malaysia TEC maps at E-region on 13/12/1999

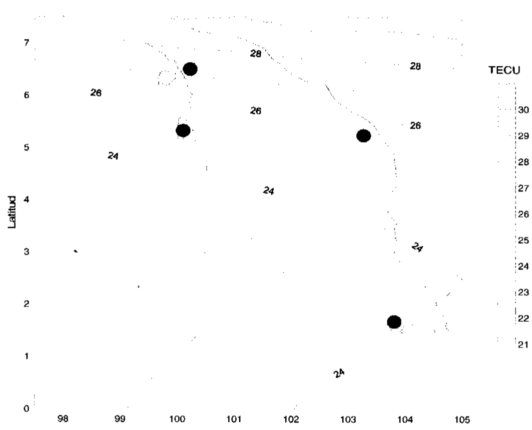

FIGURE 10: Peninsular Malaysia TEC maps at F1-region on 13/12/1999

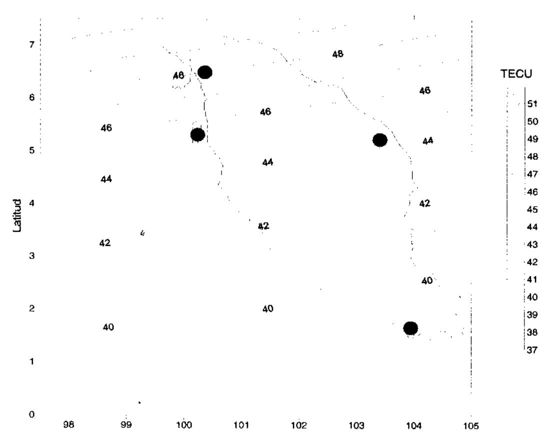

FIGURE 11: Peninsular Malaysia TEC maps at F2-region on 13/12/1999

CONCLUSION

The ionosphere is the earth's upper atmosphere which can affects the GPS signals when these signals pass through this layer. This atmospheric layer can be grouped into various regions in terms of their range of altitudes above the earth's surface (50 km and above) and their properties of reflecting electromagnetic waves. i.e. plasma ionization characteristics. Each of these regions will subsequently cause the ionospheric biases in GPS observations whereby the amounts will varies with respect to their exact boundaries with local time and prevailing geographical conditions, e.g. equatorial, mid-latitude and polar regions. One of the main ionospheric effects on GPS signals is the group (time) delay. This ionospheric time delay is mainly characterized by the TEC values. Since the ionosphere is a dispersive medium for radio waves, the corresponding TEC values can be estimated from the L1/L2 carrier phase measurements. This experiment is concerned with the estimation of TEC values with respect to major characteristics of the ionospheric regions, namely region D, E, F1 and F2. There are a number of permanent GPS networks which can be utilised for studying and monitoring the ionosphere. Here, in order to estimate the TEC values over the Malaysian region, data sets from four MASS stations were processed and analysed using the Bernese software package. From the experimental results, it has demonstrated that the TEC values are varied with respect to ionospheric layers, i.e. between 5 to 50 TECU.

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